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An all optical nanometric switch

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Abstract

Current requirements on information transfer, computation and storage demand new counterparts to the electronic components. In particular, full-optical components are currently explored. Different phenomena observed in the interaction of light with nanoparticles allow the development of this concept. In this work, we explored the possibility of creating a full optical nanometric switch to be the simplest part of the future family of components in optical nanocircuits.

In 80's, Kerker et al [1] showed that the scattering of sub-wavelength particles can be directed under certain conditions. In fact, a nanoparticle can accomplish a zero backscattering (ZB) or minimum forward scattering (MF) depending on the relationship between its material, size and incident wavelength. We have demonstrated that the Kerker conditions can be found in the visible range for several usual semiconductor materials, as Silicon, Germanium, TiO_2, GaAs, etc [2]. Playing with sizes, it is possible to obtain nanoparticles satisfying either the ZB or the MF at the same wavelength. Then, we have proposed a dimer of silicon nanoparticles [3] presenting such combination of directional scattering in the visible range. This set can produce either a maximum or a minimum of the scattered field in the area between the nanoparticles. As Kerkers' conditions are very dependent on the wavelength, we propose that a modulation of the incident wavelength can be used as switching parameter (Fig. 1). We have searched the optimum parameters of the dimer setup, in wavelength, distance between particles and their sizes, in order to make easier the fabrication for the Research Community to get an experimental Proof of Technology of these simple designs.

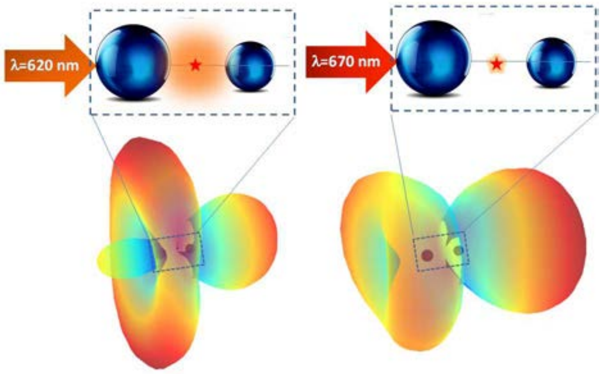

Fig. 1. Scheme of the proposed nanoswitch based on a dimer of silicon nanoparticles. Switching the incident wavelength of the light, a hotspot can be modulated in the gap between them

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References

[1] M. Kerker, D.S. Wang, and C.L. Giles. "Electromagnetic Scattering by Magnetic Spheres," J. Opt. Soc. Am. **73**, 765-767 (1983).
[2] B.García-Cámara, J.F. Algorri, A. Cuadrado, V. Urruchi, J.M. Sánchez-Pena, and R. Vergaz, "Size Dependence of the Directional Scattering Conditions on Semiconductor Nanoparticles," IEEE Photonic Technol. Lett. **27**, 2059-2062 (2015).
[3] B. García-Cámara, J. F. Algorri, A. Cuadrado, V. Urruchi, J. M. Sánchez-Pena, R. Serna, R.Vergaz. "All-Optical Nanometric Switch based on the Directional Scattering of Semiconductor Nanoparticles," J. Phys. Chem. C **119**, 19558-19564 (2015).

An all-optical nanometric switch

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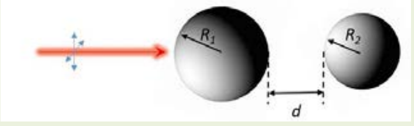
1. INTRODUCTION

Photonics is now present in a large amount of applications in the nanometric range, from the design of novel and high sensitive nanobiosensors to photonic on-chip devices [1,2].

In this work, a structure based on a **dimer of silicon nanoparticles**, **presenting directional scattering in the visible range**, was studied as a new design of an **all-optical switch**. Either a maximum or a minimum of the scattered field in the gap region are used a switching states and the modulation of the incident wavelength a switching parameter.



2. THEORY

The directional scattering of a nanostructure involves the ability to optimize the differential scattering efficiencies in certain directions. In particular the forward scattering (Q_{FS}) and radar backscattering (Q_{RBS}) efficiencies, are given by [3]:

$$Q_{FS} = \frac{1}{x^2}\left|\sum_{n=1}^{\infty}(2n+1)\left(a_n + b_n\right)\right|^2 \qquad Q_{RBS} = \frac{1}{x^2}\left|\sum_{n=1}^{\infty}(2n+1)(-1)^n\left(a_n - b_n\right)\right|^2 \qquad (1)$$

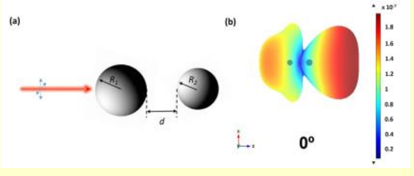
Kerker and coworkers establish that the scattering at these directions can be suppresed, in the small-particle limit, under the following conditions [4]:

$$\mathrm{Re}(a_1) = -\mathrm{Re}(b_1)\,;\, \mathrm{Im}(a_1) = \mathrm{Im}(b_1)$$
$$a_1 = b_1 \qquad (2)$$

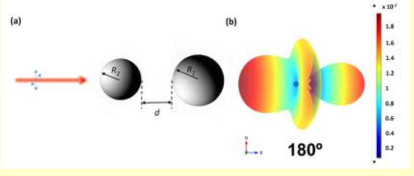
3. RESULTS

➢ Considering two Si nanoparticles (R_1=96nm, R_2=82nm) satisfying each Kerker's conditions at the same incident wavelength (λ=700nm)

A **mínimum** in the middle of the gap región



Or a **maximum**



can be obtained **depending of the arrangement** of the nanoparticles or the **incident direction**

➢A modulation of the wavelength strongly change the distribution of the electric field in the gap region, fulfilling or avoiding the Kerker's conditions.

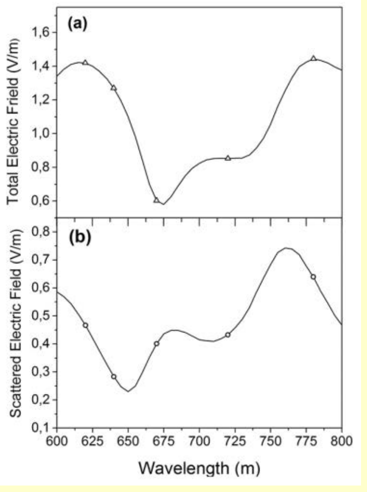


Figure 1. (a)Total and (b) scattered electric field in the middle point (near-field) of the considered nanostructure (d=120nm) as a function of the incident wavelength around that satisfying Kerker's conditions.

➢ A **strong contrast that can be used as switching states** of a futuristic all-optical nanoswitch can be observed.

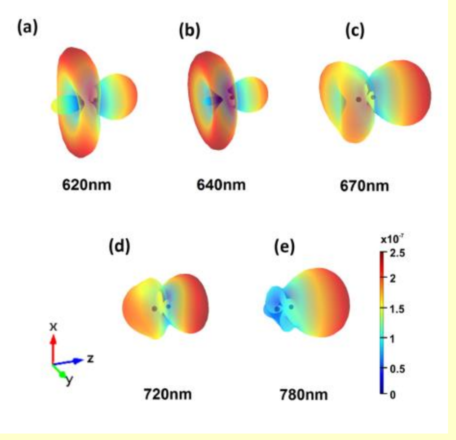


Figure 2. Spatial distribution of the scattered field of the optimum dimer in the far-field region for several incident wavelengths around that ones at which Kerker's conditions are satisfied for each nanoparticle. The interparticle distance is 120 nm.

4. CONCLUSIONS

- We explore the design of an all-optical switch using the anisotropic scattering of semiconductor nanoparticles.
- A dimer composed of two Si nanoparticles satisfying one of the Kerker's conditions at the same λ has been considered.
- Two arrangements were considered obtaining either a maximum or a minimum of the scattered field at the middle point between the particles
- A wavelength shift produces strong variations of the electric field that can be used as switching states. An optimization of the contrast can be obtained.

5. References

[1] Sepúlveda, B.; Angelomè. P.C.; Lechuga, L.; Liz-Marzán, L.M. Nanotoday **4**, 244-251 (2009).

[2] García-Cámara. B. In Communication Architectures for Systems-on-Chip; Ayala, J.L., Ed.; CRC Press: Boca Ratón, 2011; pp. 249-332.

[3] Bohren, C.F.; Huffman, D.R. Absorption and Scattering of Light by Small Particles; John Wiley & Sons: New York, 1983.

[4] Kerker, M.; Wang, D.S.; Giles C.L. Electromagnetic scattering by magnetic spheres. J. Opt. Soc. Am. **73**, 765-767 (1983).

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